

Final Scientific Report on the project:

NRA 98-OSS-08 JURRISS – Joint US/Russian Research in Space Science Program

Investigation of Solar Wind Correlations and Solar Wind Modifications Near Earth by Multi-Spacecraft Observations: IMP 8, WIND and INTERBALL-1

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The foundation of this Project is use of the opportunity available during the ISTP era to compare solar wind measurements obtained simultaneously by three spacecraft – IMP 8, WIND and INTERBALL-1 at wide-separated points.

Using these data allows us to study three important topics:

- 1) the size and dynamics of near-Earth mid-scale (with dimension about 1-10 million km) and small-scale (with dimension about 10-100 thousand km) solar wind structures;
- 2) the reliability of the common assumption that solar wind conditions at the upstream Lagrangian (L1) point accurately predict the conditions affecting Earth's magnetosphere;
- 3) modification of the solar wind plasma and magnetic field in the regions near the Earth magnetosphere, the foreshock and the magnetosheath.

Our Project was dedicated to these problems. Our research has made substantial contributions to the field and has lead others to undertake similar work.

This Final Scientific Report contents short descriptions of the results and includes the lists of conference reports and published papers.,

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Report of Results and Progress.

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Our research during the period of operation (November 1999 – July 2002) under this grant support was very successful and coincided well with the plan presented in the original Proposal Summary in 1998.

The following investigations were performed:

- 1) We developed and checked the new method of solar wind data comparison – the scattering function calculations.
The use of this method confirms rather well the results and conclusions that obtained using the linear Pearson cross-correlation procedure.
- 2) We continued comparison of IMP 8, WIND, INTERBALL-1 solar wind measurements comparison for new data intervals and developed a huge statistical base (several hundred thousands of measurements).
- 3) We selected cases with good correlations between two spacecraft but poor with the third, or with poor correlations between all three spacecraft and studied the conditions leading to such differences.
- 4) We prepared of data and developed criteria to study the dependence of correlations on the various independent factors.
Multifactor analysis was used to determine the physical and positioning factors that control the solar wind plasma and IMF correlations.
- 5) As the result of correlation study we obtained (for the first time) an estimate of the average persistence time and size of the solar wind intermediate-scale structures.
- 6) Selection was done of intervals with simultaneous multi-spacecraft observations in the undisturbed solar wind and in the foreshock and magnetosheath regions.
- 7) We studied the large solar wind ion flux variations in the foreshock and the magnetosheath in the wide range of periods (from seconds to hours). These variations are the most important solar wind modification near Earth and may play a significant role in magnetospheric disturbances.
- 8) A statistical investigation was completed of sharp and large solar wind dynamic pressure changes that are often geoeffective.
- 9) Case study and statistical analysis of the plasma correlations when large, sharp solar wind disturbances (pulses) are present using high-time resolution data. Use these results to prepare pragmatic recommendations for space weather prediction using upstream (at L1, for example) solar wind monitor data.
- 10) Analysis of historical and recent data to determine the possible solar cycle effect on the plasma correlations.
- 11) Detail study of solar wind modifications in the foreshock and magnetosheath, their origins, their frequency spectra, the relations between foreshock and magnetosheath changes, and their effects on the magnetosphere.

The data base for our study were the long time series of solar wind measurements from IMP

8 with time resolution about 1 min., WIND with time resolution about 1.5 min. and INTERBALL-1 with time resolution 1 sec.

The IMP 8 and WIND data were available for our work via our own data archive in MIT and the large archive of space data in GSFC.

The INTERBALL-1 plasma (from several instruments) and magnetic field data are conserved in Central STDA Archive of Space Research Institute (IKI) in Moscow and were also available to the US participants on the Project.

The pragmatic benefit of this work is the testing of the concept of monitoring the solar wind (and IMF) at a rather distant point from the Earth (e.g., in the well-known first libration point (L1) approximately 1.4 million km to the Sunward side of Earth) to use as input data for studies and predictions of the effect of the solar wind dynamics on Earth's magnetosphere. Such monitoring is a major part of the system of quick-look tracking of "space weather". It is thus especially important to know the "level of reliability" of such predictions.

One serious limitation of the simple idea of using a distant spacecraft to monitor the solar wind is that the solar wind can be changed dramatically near Earth's bow shock in the foreshock region. This region is observed upstream of the quasi-parallel part of the bow shock when magnetic field lines connect the spacecraft with the bow shock and is characterized by a large level of upstream wave activity, magnetic fluctuations, and streaming energetic particles (due to reflection/energization at the bow shock or leakage from the magnetosphere).

The foreshock features were intensively studied during the past 20 years, but this work dealt mainly with waves and energetic particles and not with modifications of the solar wind itself. Our study shows that there are large and fast variations of solar wind ion flux (or density) in the foreshock and these variations are in phase with magnetic field variations. This modification is important because it changes the character of the solar wind which crosses the quasi-parallel bow shock.

The next region of solar wind modification on its way to the magnetosphere is the magnetosheath. As shown during this Project, there are a lot of solar wind variations in the magnetosheath. Some of them originate in the solar wind but others (maybe the majority) are created in the magnetosheath itself. The problem is the clarification of these two types of plasma and magnetic field variations.

So, we compared simultaneous plasma and IMF parameter variations in the undisturbed solar wind and in the foreshock and in the magnetosheath using multi-spacecraft (by two or better three spacecraft) measurements. We also studied the propagation of large (and extremely large) solar wind plasma and IMF disturbances through the foreshock and the magnetosheath. From this work we obtained an estimate of the effect of solar wind modifications in the foreshock and magnetosheath on the magnetospheric behavior. According to our results this effect may be very significant and thus geoeffective.

Thus, our research has a pragmatic benefit of increasing

the reliability of forecasting models for space weather purposes.

The results of our joint investigation were presented in 30 reports at international conferences (see the list in point 2) and also 27 common papers have been published in or submitted to journals and conference proceedings (see the list in point 3).

2. List of common conferences reports.

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1. One report was presented at the International Conference "Physics of Space Growth Points and Problems", Paris–Meudon, France, January 2000.
2. Three reports were presented at the International Symposium "From solar corona through interplanetary space into Earth's magnetosphere and ionosphere: Interball, ISTP satellites and ground based observations", Kiev, Ukraine, February 2000.
3. One report was presented at the International Conference "Problems of Geocosmos–3", Sankt–Petersberg, Russia, May 2000.
3. Two reports were presented at the International Conference on "Space Weather Hazard" at Crete, Greece, June 2000.
4. Two reports were presented at the 33d COSPAR Assembly, Warsaw, Poland, July 2000.
5. Two reports were presented at the International Conference "Intercomparative Magnetosheath Study", Antalia, Turkey, September 2000.
6. One report was presented at the International Conference "Solar Maximum", Pulkovo, Russia, September, 2000.
7. Two reports were presented at the International First S–Ramp Conference, Sapporo, Japan, October 2000.
8. One report was presented at the Fall AGU–meeting, San Francisco, USA, December 2000.
9. Two reports were presented at the International Conference "Space Plasma Physics", Sheffield, UK, April 2001.
10. One report was presented at the Young Scientists Conference on Astronomy and Space Physics, Kiev, Ukraine, April 2001.
11. One report was presented at the XXVI EGS– Assembly, Nice, France, May 2001.
12. One report was presented at the International Students Conference WDS'01 "Physics of Plasma and Ionized Media", Prague, Czech Republic, June 2001.
13. Three reports were presented at the Russian Conference "Physics of solar–terrestrial relations", Irkutsk, Russia, September 2001.
14. One report was presented at the Fall AGU–meeting, San Francisco, USA, December 2001.
15. Two reports were presented at the COSPAR Colloquium "Near–Earth plasma processes – project INTERBALL and behind", Sofia, Bulgaria, February 2002.
16. Three reports were presented at the XXVII EGS– Assembly, Nice, France, April 2002.
17. One report was presented at the International Students Conference WDS'02 "Physics of Plasma and Ionized Media", Prague, Czech Republic, June 2002.
18. One report was presented at the COSPAR Colloquium "Geotail, 10th anniversary", Sagamihara, Japan, July 2002.

Totally 30 reports were presented at 18 Conferences.

3. List of common published and submitted papers.

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1. G.N. Zastenker, P.A. Dalin, A.A. Petrukovich, M.N. Nozdachev, S.A. Romanov, K.I. Paularena, J.D. Richardson, A.J. Lazarus, R.P. Lepping, A. Szabo, Solar wind structure dynamics by multipoint observations, *Phys. Chem. Earth (C)*, v.25, No.1-2, pp. 137-140, 2000.
2. Nemecek Z., J. Safrankova, L. Prech, G.N. Zastenker, K.I. Paularena, S. Kokubun, Magnetosheath study: Interball observation, *Adv. Space Res.*, v.25, No.7/8, pp.1511-1516, 2000.
3. Zelenyi L., G. Zastenker, P. Dalin, P. Eigés, N. Nikolaeva, J. Safrankova, Z. Nemecek, P. Triska, K. Paularena, J. Richardson, Variability and structures in the solar wind-magnetosheath-magnetopause by multiscale multipoint observations, *Proceedings of the ESA Workshop in London*, ESA SP-449, pp.29-38, 2000.
4. Z. Nemecek, J. Safrankova, G.N. Zastenker, P. Pisoft, K.I. Paularena, J.D. Richardson, Observations of the radial magnetosheath profile and a comparison with gasdynamic model predictions, *Geophys. Res. Lett.*, v.27, No.17, pp.2801-2804, 2000.
5. G.N. Zastenker, P.A. Dalin, K.I. Paularena, J.D. Richardson, F. Dashevskiy, Solar wind correlation features obtained from multi-spacecraft study, *Adv. Space Res.*, v.26, No.1, pp.71-76, 2000.
6. P.A. Dalin, A.V. Dmitriev, Yu.V. Orlov, K. Paularena, J.D. Richardson, M.O. Ryazantseva, G.N. Zastenker, Multifactor analysis of factors controlling the solar wind correlations with the use of artificial neural network technique, *Proceedings of Intern. Symposium "From solar corona through interplanetary space into Earth magnetosphere and ionosphere: Interball, ISTP satellites and ground-based observations"*, Kyiv, Ukraine, 2000, pp. 245-248.
7. P.A. Dalin, G.N. Zastenker, K.I. Paularena, J.D. Richardson, Estimation of solar wind plasma correlation length using multipoint measurements, *Proceedings of Intern. Symposium "From solar corona through interplanetary space into Earth magnetosphere and ionosphere: Interball, ISTP satellites and ground-based observations"*, Kyiv, Ukraine, 2000, pp. 249-252.
8. P. Eigés, G. Zastenker, M. Nozdachev, N. Rybjeva, J. Safrankova, Z. Nemecek, Multipoint observations of small-scale solar wind structures in the Earth's foreshock region, *Proceedings of Intern. Symposium "From solar corona through interplanetary space into Earth magnetosphere and ionosphere: Interball, ISTP satellites and ground-based observations"*, Kyiv, Ukraine, 2000, pp. 253-256.
9. P.E. Eigés, G.N. Zastenker, M.N. Nozdachev, J. Safrankova, Z. Nemecek, N.E. Rybeva, Fast Variations of solar wind ion

- flux and of the magnetic field in the foreshock: 2. Quasiharmonic structures, *Kosmich. Issled.* (in Russian), v.38, N 5, pp.469–474, 2000.
10. P.A. Dalin, G.N. Zastenker, K.I. Paularena, J.D. Richardson, What features become clear by simultaneous multispacecraft observations of solar wind and IMF structures, *Astrophysics and Space Science*, v. 277, pp. 323–324, 2001.
 11. Peter Dalin, Georgy Zastenker, Karolen Paularena, John Richardson, The main features of solar wind plasma correlations of importance to Space Weather strategy, *Journal of Atmospheric and Solar–Terrestrial Physics*, v.64, pp. 737–742, 2002.
 12. P.A. Dalin, G.N. Zastenker, M.N. Nozdrachev, I.S. Veselovsky, The properties and possible origins of the large and sharp impulses in the solar wind, submitted to *Intern. Journ. of Geomagn. and Aeron.* (in press).
 13. P. Eiges, G. Zastenker, M. Nozdrachev, N. Rybyeva, J. Safrankova, Z. Nemecek, Small scale solar wind ion flux and IMF quasi-harmonical structures in the Earth's foreshock: Interball-1 and Magion-4 observations, submitted to *Adv. Space Res.* (in press).
 14. P.A. Dalin, G.N. Zastenker, K.I. Paularena, J.D. Richardson, A Survey of large, steep solar wind dynamic pressure changes observed by INTERBALL-1 and IMP 8, *Annales Geophysicae*, v.20, pp. 293–299, 2002.
 15. G.N. Zastenker, M. N. Nozdrachev, J. Safrankova, Z. Nemecek, K.I. Paularena, J.D. Richardson, R.P. Lepping, T. Mukai, Multispacecraft measurements of plasma and magnetic field variations in the magnetosheath: comparison with Spreiter models and motion of the structures, *Planetary and Space Sciences*, v.50, No.5/6, 2002.
 16. M.O. Riazantseva, P.A. Dalin, G.N. Zastenker, Statistical study of the sharp and large solar wind ion flux changes by INTERBALL-1 satellite measurements. *Proceedings of WDS'01 Conference, Part II, Physics of plasmas and ionized media*, pp.233–238, 2001
 17. P.E. Eiges, G.N. Zastenker, J. Safrankova, Z. Nemecek, N.A. Eismont, Statistical approach to the estimation of the average correlation length and propagation velocity of the middle-scale plasma variations in the Earth's foreshock region, *Kosmich. Issled.* (in Russian), v.39, N 5, pp.463–469, 2001.
 18. M.O. Riazantseva, P.A. Dalin, A.V. Dmitriev, YU.V. Orlov, K.I. Paularena, J.D. Richardson, G.N. Zastenker, A multifactor analysis of parameters controlling solar wind ion flux correlations, using an artificial neural network technique, *Journ. of Atmospheric and Solar–Terrestrial Physics*, v.64, pp. 657–660, 2002.
 19. P.E. Eiges, G.N. Zastenker, J. Safrankova, Z. Nemecek, N.A. Eismont, Statistical approach to the foreshock middle-scale plasma structure "effective" velocity determination, *Proceedings of the Sheffield Space Plasma Meeting*, ESA SP-492, pp.65–68, 2001.
 20. P.E. Eiges, V.E. Eiges, Multipoint measurements approach to

evaluation of small-scale quasiharmonic structures velocity in the Earth's foreshock. Case study, Proceedings of the Sheffield Space Plasma Meeting, ESA SP-492, pp.73–75, 2001.

21. Dalin, G.N. Zastenker, J.D. Richardson, Orientation of middle-scale solar wind plasma structures, *Kosmich. Issled.* (in Russian), v.40, N 4, pp.343–348, 2002.
22. N.N. Shevyrev, G.N. Zastenker, J. Safrankova, Z. Nemecek, M. Gaiosh, J.D. Richardson, Large and fast changes of the magnetosheath parameters. 3. Amplitudes and radial profiles of low and high frequency plasma and field variations, *Kosmich. Issled.* (in Russian), v.40, N 4, pp. 361–373, 2002.
23. G.N. Zastenker, P.A. Dalin, M.O. Riazantseva, Reliability of the prediction of solar wind and IMF disturbances by distant monitor observations, *Solar–Terrestrial Physics* (in Russian), N 2, pp. 64–67, 2002.
24. M.O. Riazantseva, P.A. Dalin, G.N. Zastenker, Statistical analysis of the sharp and large solar wind ion flux (density) pulses by Interball–1 data, *Solar–Terrestrial Physics* (in Russian), N 2, pp. 89–92, 2002.
25. G.N. Zastenker, N.N. Shevyrev, M.N. Nozdrachev, Large plasma and magnetic field variations in the magnetosheath as possible source of magnetosphere disturbances, *Solar–Terrestrial Physics*, (in Russian), N 2, pp. 187–189, 2002.
26. Riazantseva M. O., Dalin P.A., Zastenker G.N., Orientation of the sharp solar wind plasma fronts, WDS'02, Proceedings of Contributed papers: Part II – Physics of Plasmas and Ionized Media, ed. by J. Safrankova, Praha, Matfyzpress, pp.238–243, 2002.
27. N. N. Shevyrev, G. N. Zastenker, M. N. Nozdrachev, Z. Nemecek, J. Safrankova, and J. D. Richardson, High and low frequency large amplitude variations of plasma and magnetic field in the magnetosheath: radial profile and some features, submitted to *Adv. Space Res.* (in press).

